VIII International Conference on Computational Plasticity
COMPLAS VIII
E. Oñate and D. R. J. Owen (Eds)

ON THE NUMERICAL MODELLING OF FORMING PROCESSES USING THE PARTICLE FINITE ELEMENT METHOD

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Key words: Particle methods, Powder transfer, Forming Processes

Summary. *The aim of this work is to show the potential of the Particle Finite Element Method (PFEM) in the simulation of the powder transfer stage, in powder metallurgy industrial processes. The most innovative aspects of the work are: a) the intensive use of the particle finite element method technology to trace the motion of a representative set of particles and b) the solution of inherent problems associated to the transfer information between different configurations.*

1 INTRODUCTION

Although the finite element method[1] is still one of the most powerful tools used in engineering analysis, it exhibits some disadvantages in problems where very large strains and displacements occur. These difficulties are related to the appearance of high mesh distortions typical of forming processes (metal machining, powder transfer, extrusion, rolling and others). As a consequence Jacobian determinants become negative at a number of sampling points during the process, and make impossible to continue the calculation. In order to overcome this problem, other techniques have been investigated. Recently, meshless methods combined with optimal connectivity generators, as Delaunay triangulations, have been successfully explored in Lagrangian fluid problems[2]. This technical combination is known as Particle Finite Element Method (PFEM).

The method defines the continuum mechanics behavior of the solid in terms of a finite number of particles (of infinitesimal size) from which the behavior of the remaining particles is described by interpolation. The process of calculation, the actualization of the resulting fields and the setting of new initial conditions are repeated at each time step of the simulation.

2 NOVEL NUMERICAL STRATEGY. PFEM METHOD

2.1 Problem formulation

Let $B = \{X_i; i:1...N_p\}$ a finite set of particles X_i that we select to model the continuum medium. Let $x_i = x(X_i,t)$ the particle position function, at time t, of the particle X_i, and $v(X_i,t)$ and $a(X_i,t)$ the velocity and acceleration vectors of the same particle.

The associated dynamic problem consist of finding the displacements field, $,u(X_i,t)$ along time defined by the momentum equation (1).

$$Ma + F^{\text{int}}(u) - F^{ext}(u) = 0 \tag{1}$$

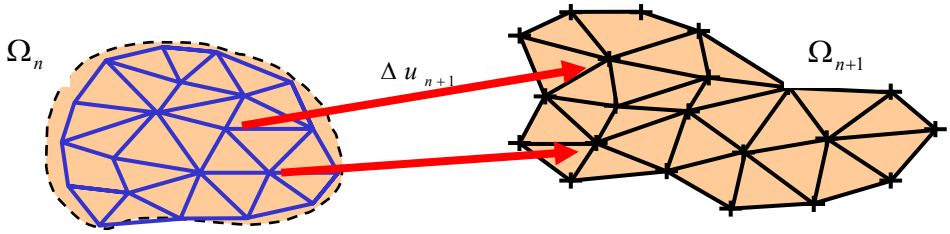

Fig. 2.1 Initial and current configuration and connectivities on the same set of particles

Completing the dynamic problem we consider the initial conditions $u(X_{i,}0) = u_0$, $v(X_i,0) = v_0$ and $a(X_i,0) = a_0$. Time integration is carried out by a standard Newmark integration method[1], which that can be expressed as follows:

$$\begin{aligned} &M_{n+1}a_{n+1} + K_{n+1}u_{n+1} = F^{ext}_{n+1} \\ &u_{n+1} = u_n + \Delta t v_n + \frac{1}{2}\Delta t^2\left[(1-2\beta)a_n + 2\beta a_{n+1}\right] \\ &v_{n+1} = v_n + \Delta t\left[(1-\gamma)a_n + \gamma a_{n+1}\right] \end{aligned} \tag{2}$$

where M_{n+1} is the mass matrix, K_{n+1} the stiff matrix, F^{ext}_{n+1} are the external forces (volumetric and contact forces), Δt the time step and γ, β are the Newmark integration parameters.

2.2 Numerical strategy

Once the new variable fields arisen from the calculation are known, their update is performed. For high deformation processes, if the reference connectivities are kept constant, the convected positions translate into highly distorted meshes. In order to avoid this problem, a new optimal connectivity must be computed. Keeping unaltered the representative particles of the domain, but considering updated spatial positions, its Voronoi diagram and Delaunay triangulations are carried out. The result is new particle connectivity that presents an undistorted spatial discretization, which allows continuing the calculations with a well-placed initial conditions problem. Next, new value variable fields must be transferred between

reference and current configurations. This is performed in a direct way making a local smoothing and "transporting" the information by means of the particles to the updated position. This transfer method generates fewer errors than in the conventional one, because a nodally exact variable transport is performed during each time step. Finally an interpolation step of the problem variables set, to the new configuration sampling points, is carried out, and the calculation goes on.

Considering a general constitutive model, as the one used by the authors[3], for solving an incremental dynamic problem, the steps shown in the following chart are followed:

Step 1: Initialization: Set of v_n, a_n and $\overline{q}_{n+1}$ (set of internal variables) at time t

Step 2: Connectivities generation: Using Delaunay triangulations techniques, a new connectivity relationship between particles is obtained[2]

Step 3: Interpolation of new sampling points: for the updated particle positions and connectivities, new interpolations to sampling points is performed

Step 4: Solution of incremental non linear general problem: Under the connectivity stated in step 2, equation (1) is solved by a standard FEM method[1]

Step 5: Nodal upload and information transport: Once solved the currently time problem, the new nodal variable fields are updated.

Step 6: Setting of new initial conditions: The convected set of variables are considered as initial conditions at time $t+1$, then the process goes to step 2.

Step 7: End of process

3 MODELING THE TRANSFER STAGE IN POWDER FORMING PROCESSES

The powder transfer stage is an important part of powder forming process. Recently, its practical importance in the final obtained compaction density distribution has been recognized. Obtaining non-homogeneous densities in this stage of the process could cause serious defects in finished mechanical pieces. Numerical simulation can be used to optimize the kinematics of punches during transfer stage, helping to obtain more homogeneous density distributions before the pressing stage.

In order to show the performance of PFEM in modeling powder transfer processes a rectangular shaped chamber transfer, displayed in figure 3.1 is used. Box dimensions are 100 mm height and 50 mm width. Upper and lower punches are both of the same width, 10 mm, and the transfer distance between them is kept constant in 30 mm. Punches displacements are 50 mm during 1 second.

The material is iron powder with an apparent density of 3,4 gr/cm^3, and it was divided in 20 layers of 5 mm height each one to facilitate the particle tracking during the process. In figure 3.2 experimental and numerical results are compared. They show a good agreement and display the potential benefits of the PFEM technology in this type of problems.

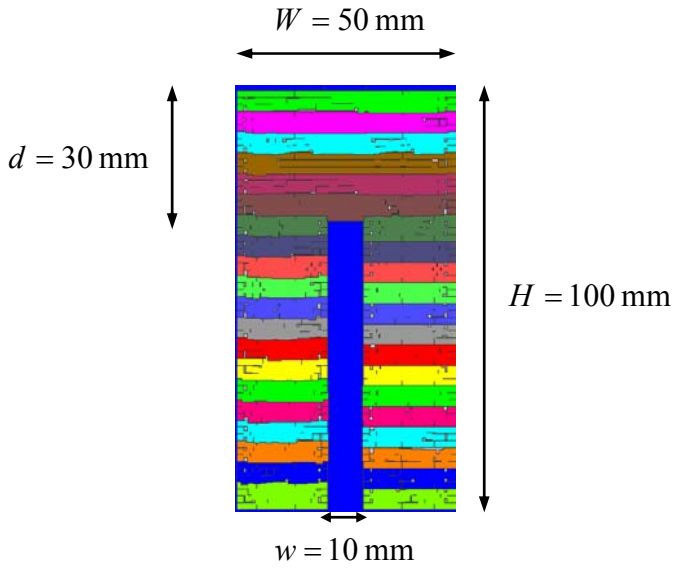

Fig. 3.1 Geometry and initial configuration of the transfer chamber

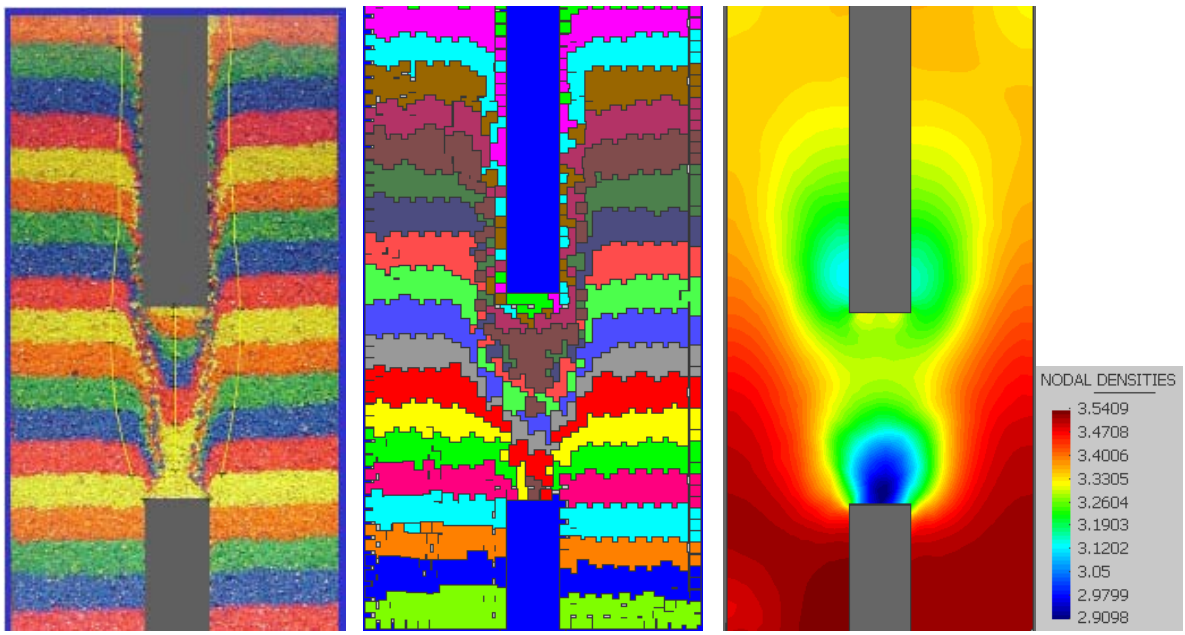

Fig. 3.2 Displacements field and density field after powder transfer stage. Left): experimental distribution of layers after the transfer process, center): numerical distribution of layers and right): density distribution.

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